Numerical Optimization Predicts Human Manipulation Performance When Rotating an Object Through the Gravity Field.
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The mechanical complexities of rotating an object through the gravity field present a formidable challenge to the human central nervous system (CNS). The mechanical redundancy of multi-fingered manipulation renders static solutions indeterminate, and the redundant finger forces have dual roles of weight support and slip prevention. Despite these complexities the CNS solves these problems with ease.

The finger force patterns (and derivatives thereof) selected by eight human subjects were documented for one-, two-, and four-fingered rotational manipulation. Numerous mechanically 'unnecessary' behaviors were observed. These included: non-zero tangential forces for horizontal handle orientations and large internal forces for all orientations (θ). Additionally, none of the investigated measures were stabilized across θ, even trigonometrically. All measures nonetheless varied systematically (and sometimes symmetrically) with θ. This suggests that the CNS selects forces non-arbitrarily.

While the 'safety margin' (*SM*) measure has been used in the prehension literature to describe consistencies in grasp performance, we demonstrate here that the *SM* is an inappropriate measure for both non-vertical and multi-finger grasps. The current study rather accounted for the observed human behavior using numerical optimization of a simple mechanical model (Figure 1). Optimization results closely paralleled experimental observations (Figure 2) with a more-or-less constant 'optimization scaling factor' (*OSF*). These data suggest that at least two CNS processes are responsible for the finger force synergies of manipulation: (1) Determination of an optimal solution, and (2) Scaling the forces to an appropriate *OSF*. More sophisticated biomechanical models and/or objective functions might account more completely for the forces exerted by humans during rotational manipulation.
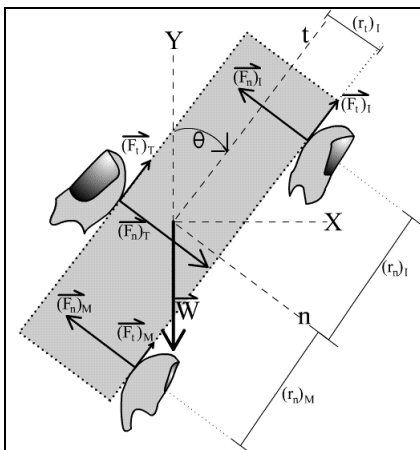

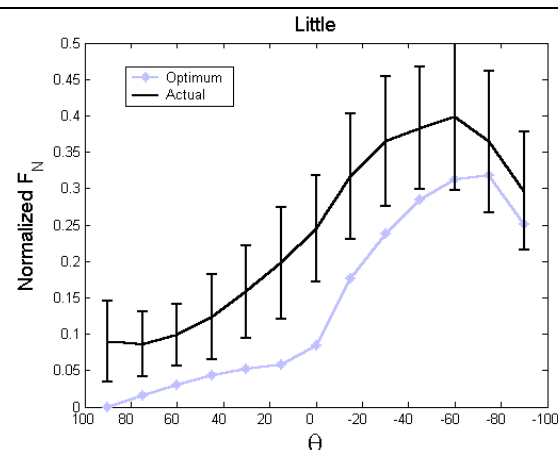Figure 1. Mechanical model of rotational manipulation.

Figure 2. Optimum (light) and observed (dark) normal forces across θ for the Little finger.